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**SUBJECT:** NAGS Documentation: A Computer  
Routine for Targeting the NC/NH/NSR  
Rendezvous Profile - Case 610

**DATE:** September 30, 1970

**FROM:** C. O. Guffee  
R. C. Purkey

**ABSTRACT**

The NC/NH/NSR rendezvous maneuvers are designed to move a vehicle from any arbitrary point into a coelliptic orbit at the desired altitude such that the vehicle will arrive at a given elevation angle with respect to the target at the desired time.

A UNIVAC 1108 FORTRAN V subroutine capable of targeting these maneuvers has been written for use with Bellcomm's Navigation and Guidance Simulator (NAGS). This routine is capable of computing precision integrated or conic solutions. The NC/NH/NSR targeting routine can be used to target the first two maneuvers in the Skylab Rendezvous Profile.

This memorandum is one of the series which will ultimately be collected to form the documentation for the Navigation and Guidance Simulator.

(NASA-CR-113928) NAGS DOCUMENTATION - A  
COMPUTER ROUTINE FOR TARGETING THE NC/NH/NSR  
RENDEZVOUS PROFILE (Bellcomm, Inc.) 21 p



00/13

FF No. 602	(PAGES)	(CODE)
	CR-113928	
	(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

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MEMORANDUM FOR FILEI. Introduction

The objective of the NC/NH/NSR rendezvous maneuver sequence is to obtain, at a specified time, a desired phase and height relationship of an active rendezvous vehicle relative to a passive vehicle. The individual maneuver objectives are as follows:

1. NC - a phase maneuver designed to adjust the catch-up rate of the active vehicle with respect to the passive vehicle,
2. NH - a height maneuver designed to obtain the desired coelliptic altitude for the active vehicle, and
3. NSR - a maneuver to place the active vehicle into a coelliptic orbit.

A possible NC/NH/NSR profile is shown in Figure 1. Figure 1 is a relative motion plot of the active vehicle with respect to the passive vehicle in local vertical curvilinear coordinates centered in the passive vehicle with the horizontal axis along the passive vehicle orbit.

The Skylab rendezvous profile shown in Figure 2 contains a modified NC/NH/NSR sequence. This sequence is comprised of two NC maneuvers (shown as NC1 and NC2), a Lambert-targeted corrective combination maneuver (NCC) (described in Reference 1) in place of the NH maneuver, and the NSR maneuver. While the Skylab rendezvous does not follow the exact sequence of the NC/NH/NSR rendezvous, the targeting of the NC maneuvers is identical. The NSR maneuver in the Skylab rendezvous is targeted using the method of Reference 1, since it includes an out-of-plane correction in addition to establishing the coelliptic orbit.

The NC/NH/NSR targeting routine was written for use with Bellcomm's Navigation and Guidance Simulator (NAGS). This routine is capable of targeting the three maneuvers

using either precision integration with a full gravity model, or conic approximations for propagation of the orbits. Both capabilities are needed in order to study the rendezvous maneuvers as they would be computed by the RTCC or by the on-board computer. This memorandum then, describes the NC/NH/NSR rendezvous maneuvers and the authors' version of a routine that targets them.

## II. Discussion of the NC/NH/NSR Rendezvous Maneuvers

To further define the NC/NH/NSR maneuvers and to limit the unknowns involved, several constraints are imposed. These constraints are divided into two categories: those dealing with the maneuvers themselves and those involving the complete NC/NH/NSR rendezvous sequence. The constraints on the maneuvers are:

1. The NC and NH delta-v's are constrained to be in the orbit plane, and normal to the position vector.
2. All maneuvers occur at an apsidal point in the orbit.
3. Following the NSR maneuver, the vehicles must be in coelliptic orbits.
4. The active vehicle will arrive at the desired TPI conditions of elevation angle, differential altitude, and time.

The constraints on the NC/NH/NSR sequence are:

1. The numbers of half orbits between NC and NH and between NH and NSR can be varied so long as the total NC to TPI time is not violated.
2. The minimum altitude at which NH can occur is that of the perigee of the insertion point.
3. There must be an odd number of half orbits between NH and NSR.

In order to obtain a solution for the NC maneuver, all three maneuvers must be considered along with all of the constraints. Each of the three maneuvers have, in general, four associated unknowns -- the three components of the velocity required and the time of the maneuver. The constraints and

target conditions, together with three additional inputs, make a unique solution possible. The three additional inputs specify the particular time at which the NC maneuver is to be performed, the number of half orbits between NC and NH, and the number of half orbits between NH and NSR. The solution technique lies in iterating on the NC maneuver delta-v to satisfy the desired time of arrival at the desired TPI state. Specifying a particular value of NC delta-v, together with the number of half orbits between NC and NH determines the time and the arrival state vector at the NH maneuver point. This pre-NH state vector, the desired coelliptic altitude difference, and two of the constraints -- requiring an odd number of half orbits between NH and NSR and requiring only a horizontal velocity component of delta-v -- uniquely determine the NH delta-v. Therefore, NH must raise the opposite apside to the desired coelliptic altitude with a horizontal component of delta-v (i.e., a Hohmann transfer). This delta-v at NH and the number of half orbits required between NH and NSR specify the arrival state vector at NSR. The pre-NSR state vector, together with the constraint that the NSR maneuver must place the vehicle into a coelliptic orbit, make possible a unique solution for the NSR maneuver delta-v. Propagation of the post-NSR state vector forward in time until the desired TPI line-of-sight elevation angle is achieved produces a value of time which may or may not match the desired time. The problem is repeated with different values of NC delta-v until the desired time is achieved.

The values for the three additional input parameters are selected by the "user" and selection of "wrong" values will generally be grossly obvious. The key parameter to watch is the active vehicle altitude one-half orbit after the NC maneuver. The altitude should be equal to or greater than the pre-NC perigee and equal to or lower than the coelliptic altitude. Otherwise, at least one of the three maneuvers will be retrograde and the total delta-v costs will be rather high. It should be emphasized, however, that more than one set of values for these input parameters may produce the desired rendezvous. Therefore operational considerations, such as the tracking available, are usually taken into account when selecting these input values.

The NH maneuver of this sequence is targeted after implementation of the NC maneuver. At this point in the sequence, it may not be possible to achieve the desired end conditions if there were navigation or implementation errors for the NC maneuver. Therefore the NH maneuver only achieves the desired coelliptic altitude. This maneuver is computed as a Hohmann transfer in which the desired altitude, an odd number of half orbits later, is obtained by a horizontal delta-v.

The NSR maneuver is targeted after NH is implemented. This maneuver can do nothing to adjust the coelliptic altitude or to insure that the desired TPI conditions are met. The maneuver will only place the vehicles in coelliptic orbit at the input time. This maneuver uses the MIT coelliptic velocity expression (Reference 2).

### III. The NC/NH/NSR Rendezvous Targeting Routine

The NC/NH/NSR rendezvous targeting routine was written in FORTRAN V for the UNIVAC 1108 computer. This subroutine, named THREE, was designed for use with Bellcomm's Navigation and Guidance Simulator. Appendix A contains the input and output parameter code names and the list of which parameters are required for each maneuver. Appendix B contains a flow diagram of the targeting routine. The following discussion outlines several features implemented in the authors' targeting subroutine.

The authors developed the routine to have the capability to target a rendezvous using either precision integration with a full gravity model, or conic projections over a spherical earth. The non-spherical gravity model, however, causes the planes of the active and passive vehicles to precess at different rates and hence the two orbital planes are not aligned at all instances of time. This non-spherical gravity also complicates the problem of determining the line-of-apsides of an orbit. Thus, the inclusion of the non-spherical gravity model brought about the addition of certain approximations relating to the solution of these two problems.

The different rates of precession depend on initial planar relationship at NC, the relative orbital altitude, and the inclinations. Since the NC/NH/NSR maneuvers are powerless to add an out-of-plane delta-v to correct for this planar difference, a plane change maneuver must be added to the rendezvous in order to arrive at TPI in-plane. For this reason, the NC targeting assumes that the active vehicle state after the NSR maneuver is coplanar with the passive vehicle. This is accomplished by projecting the active vehicle position and velocity vectors into the passive vehicle plane at the NSR point. The projected vectors are then linearly scaled in order to preserve the original magnitudes. This procedure was tested and determined to have negligible effect on any of the delta-v's required.

The rendezvous targeting presumes that maneuvers will be separated by integer multiples of 180° of motion

and therefore on a maneuver line in the orbit plane. However, since the orbit plane precesses, the maneuver line established at NC must be projected into the instantaneous planes at NH and at NSR. Rotation of the line of apsides due to perturbations have no effect on these maneuvers. Studies of rendezvous requiring up to sixteen orbits indicate that this is a satisfactory operational method.

The iteration loop in the authors' routine for computing the NC delta-v differs in one detail from that described in Section II. The authors' routine first integrates the passive vehicle to the TPI time. The active vehicle state at TPI is then constructed using the specified TPI conditions. This active state is then projected backwards in time to the maneuver line. This locates the NSR maneuver. This active state at NSR is then saved for use in the NC iteration. The routine iterates for the delta-v at NC using this NSR state as the target point instead of advancing each trial state to the TPI time to check the elevation angle. This is done to save computer time in the maneuver targeting.

The targeting subroutine uses a Newton-Raphson iteration technique for the NC maneuver. This iteration loop requires two initial points and then will supply the trial values for NC delta-v. The loop is initialized by using a trial value for NC delta-v that would raise, in conic motion, the altitude one half orbit from NC to the average of the NC and NSR altitudes. The second trial differs from the first trial by 10 ft/sec in the direction to lessen the error. Once initialized, the iteration will usually converge within three loops.

As mentioned earlier, this subroutine is capable of computing either a conic or a precision integrated rendezvous. In the case of the precision solution, however, the conic solution is also computed in order to provide the initial estimates and sensitivities for the precision iteration.

*C. O. Guffee*  
C. O. Guffee

*R. C. Purkey*  
R. C. Purkey

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RCP

Attachments

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### REFERENCES

1. NAGS Documentation: The NCC/NSR Rendezvous Maneuvers Targeting Routine, Bellcomm Memorandum for File B70 08032 C. O. Guffee, R. C. Purkey, August 18, 1970.
2. Guidance System Operations Plan for Manned CM Earth Orbital and Lunar Mission Using Program Colossus 2E, Section 5, Guidance Equations (Rev. 10), March 1970, MIT, Charles Stark Drake Laboratory.
3. UNIVAC 1108 FORTRAN V Version of MIT Conic Subroutines Used in Apollo Guidance Computer, Bellcomm Memorandum for File B69 07032, C. O. Guffee, J. C. Gurasich, July 10, 1969.

DISTANCE BEHIND TARGET

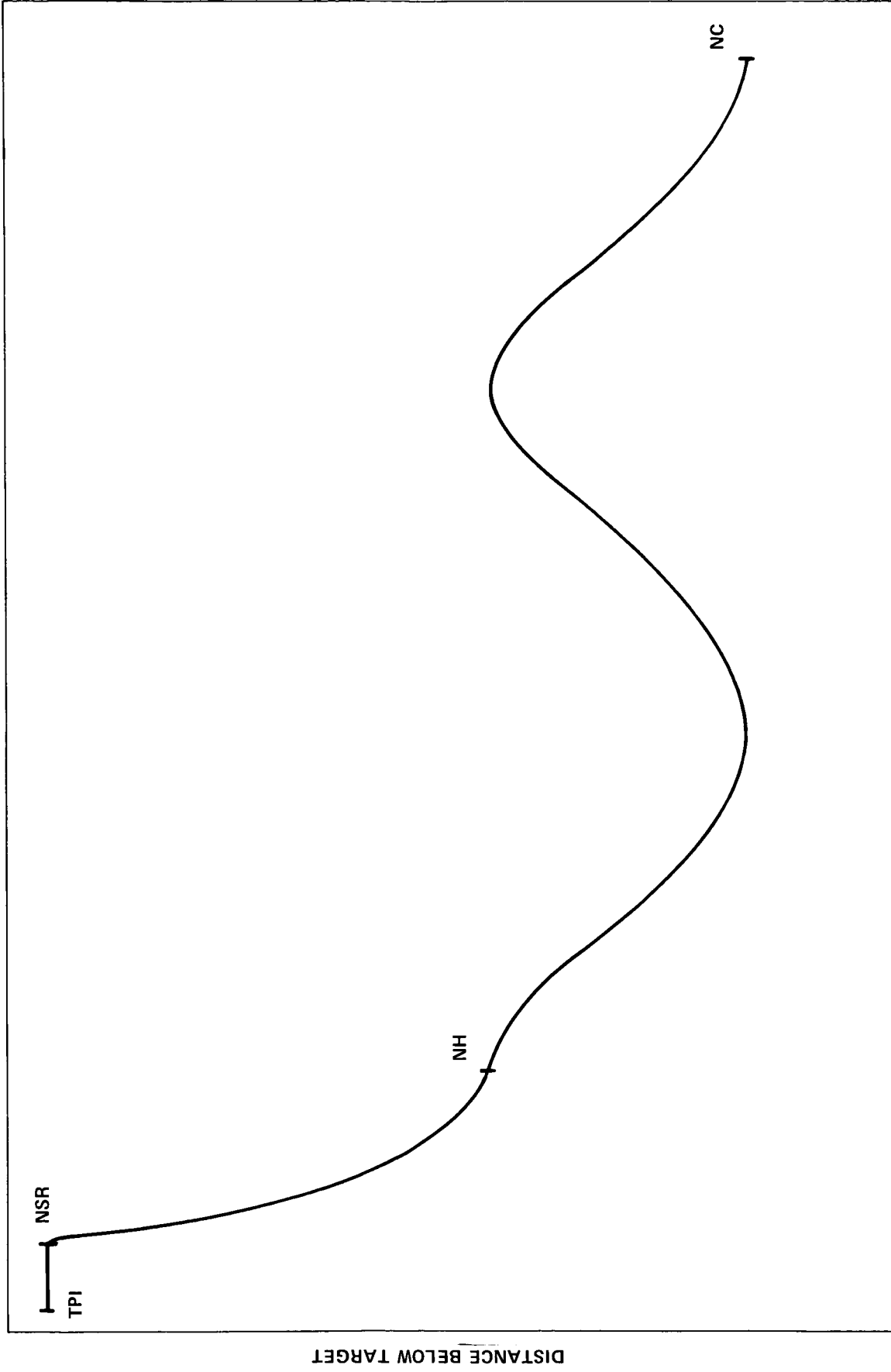


FIGURE 1 - NC/NH/NSR RENDEZVOUS SEQUENCE



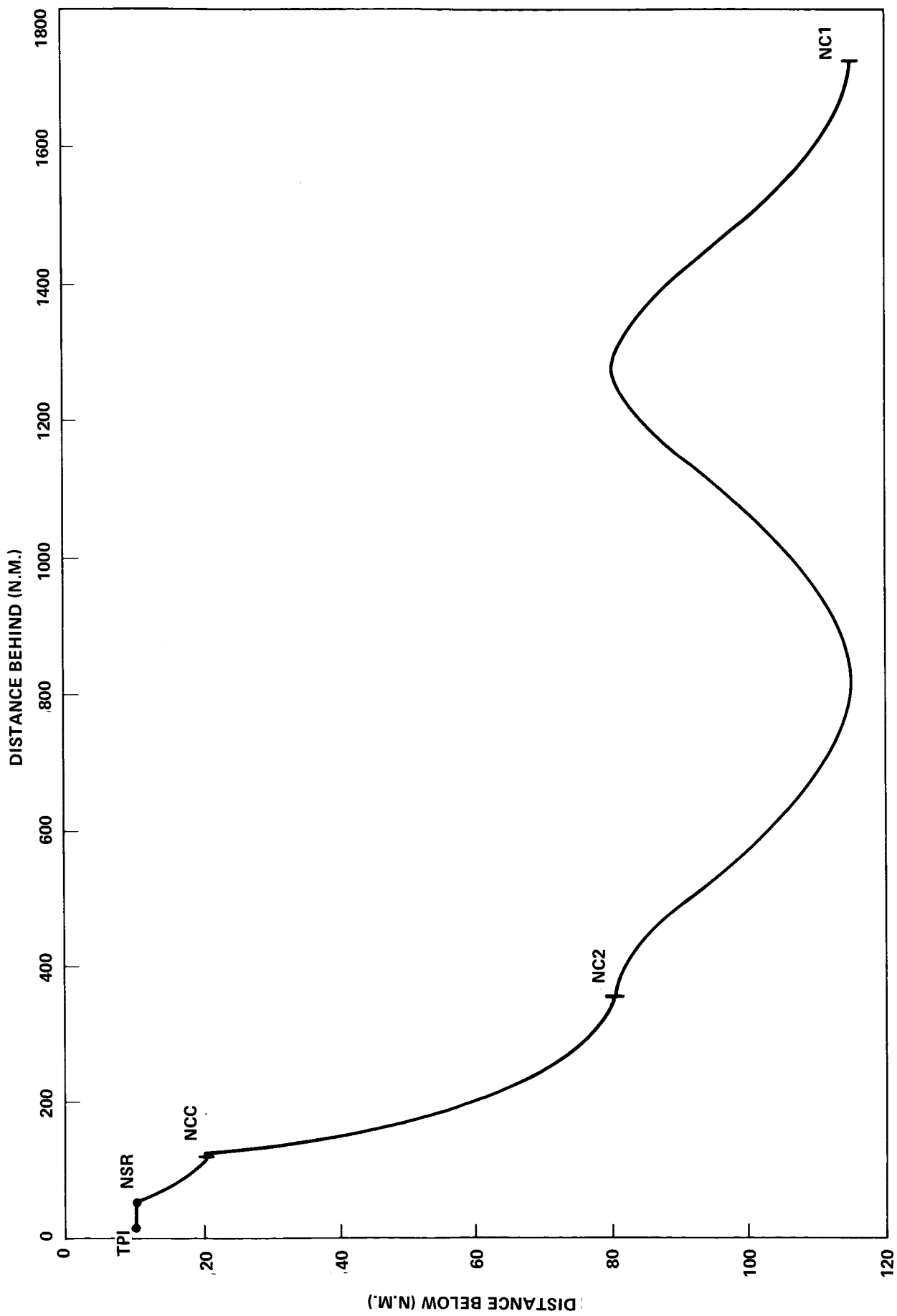


FIGURE 2 - THE PROPOSED RENDEZVOUS PROFILE FOR SKYLAB

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## APPENDIX A

The input and output variables required for the various maneuvers computed by subroutine THREE are:

### NC Maneuver

#### INPUT:

MANEUV - 1 for NC maneuver  
IA - pointer to active state vector  
IP - pointer to passive state vector  
TNCI - time of the NC maneuver (sec)  
APClH - desired number of half periods from NC to NH  
APHSR - desired number of half periods from NH to NSR  
(must be odd)  
DELTAH - coelliptic altitude difference (nm) - positive  
for coelliptic orbit below target orbit  
TTPI - time of TPI (sec)  
ELLV - elevation angle desired at TPI (degrees)  
PMU - gravitational constant ( $\text{ft}^3/\text{sec}^2$ )  
IPREC - precision flag: =1, return precision solution,  
=0, return conic solution  
IPRNT - print indicator: 1 - print variables within  
targeting routine (see separate list); 0 - do  
not print

#### OUTPUT:

DLVNC1 - The delta-v required at NC expressed in local  
vertical coordinates of the active vehicle at  
NC time. The components are (up, forward, out  
of plane) (ft/sec)  
TNH - The computed time of the NH maneuver (sec)  
TNSR - The computed time of the NSR maneuver (sec)

NH Maneuver

## INPUT:

MANEUV - 2 for NH maneuver  
IA - pointer to the active state vector  
IP - pointer to the passive state vector  
APHSR - number of half periods from NH to NSR  
DELTAH - desired differential altitude in coelliptic orbit  
(nm) - positive for coelliptic altitude below  
target orbit  
TTPI - time of TPI maneuver (sec)  
PMU - gravitational constant ( $\text{ft}^3/\text{sec}^2$ )  
IPREC - precision flag: =1, return precision solution  
=0, return conic solution  
IPRNT - print indicator: 1 - print variable within  
targeting routine (see separate list); 0 - do  
not print  
TNH - time of the NH maneuver (sec)

## OUTPUT:

DLVNH - The delta-v required at NH expressed in local  
vertical coordinates of the active vehicle at  
NH time. The coordinates are (up, forward,  
out of plane) ( $\text{ft}/\text{sec}$ ).  
TNSR - Computed time of the NSR maneuver (sec)

NSR Maneuver

## INPUT:

MANEUV - 3 for the NSR maneuver  
IA - pointer to active state vector  
IP - pointer to passive state vector  
TNSR - time of the NSR maneuver (sec)  
TTPI - time of the TPI maneuver (sec)  
PMU - gravitational constant ( $\text{ft}^3/\text{sec}^2$ )  
IPRNT - print indicator: 1 - print variables within  
targeting routine (see separate list); 0 - do  
not print

## OUTPUT:

DLVNSR - The delta-v required at NSR expressed in local  
vertical coordinates of the active vehicle at  
NSR time. The coordinates are (up, forward,  
out of plane) ( $\text{ft}/\text{sec}$ )

The variables printed when the flag IPRNT is set equal to 1 are:

NC Maneuver

RANSR - position vector at NSR (ft)  
VANSR - velocity vector at NSR (ft/sec)  
TNSR - time of NSR (sec)  
ANG1 - central angle from NSR to TPI (deg)  
ANG2 - ANG1+180° (deg)  
VBURN - position vector of MANEUVER line (unit vector)  
DLVNC1 - delta-v required at NC maneuver (ft/sec)  
DLVNH - delta-v required at NH maneuver (ft/sec)  
DLVNSR - delta-v required at NSR maneuver (ft/sec)  
TNC1 - time of NC1 maneuver (sec)  
TNH - time of NH maneuver (sec)  
TTPI - time of TPI maneuver (sec)  
XTNSR - time arrive at target NSR point (sec)  
RA2 - position vector at NH (ft)  
VA2 - velocity vector at NH (ft/sec)  
RA3 - position vector at NSR (ft)  
VA3 - velocity vector at NSR (ft/sec)

NH Maneuver

ICOUNT - iteration counter  
TEMP3 - error in height (altitude now -altitude desired) (ft)  
DVCOR - change in delta-v at NH for this iteration (ft/sec)  
TEMP4 - error in altitude of last iteration (ft)  
DV1 - total delta-v required (ft/sec)

NSR Maneuver

AA - semi-major axis of the active vehicle (ft)  
AP - semi-major axis of the passive vehicle (ft)  
TV1 - position vector of active state at NSR time (ft)  
TV2 - velocity vector of active state at NSR time (ft/sec)

NSR Maneuver (cont'd)

- TV3        - position vector of passive state at NSR  
             time (ft)
- TV4        - velocity vector of passive state at  
             NSR time (ft/sec)
- VAV        - vertical velocity required for the  
             active vehicle at NSR (ft/sec)
- VAH        - horizontal velocity required for the  
             active vehicle at NSR (ft/sec)

APPENDIX B

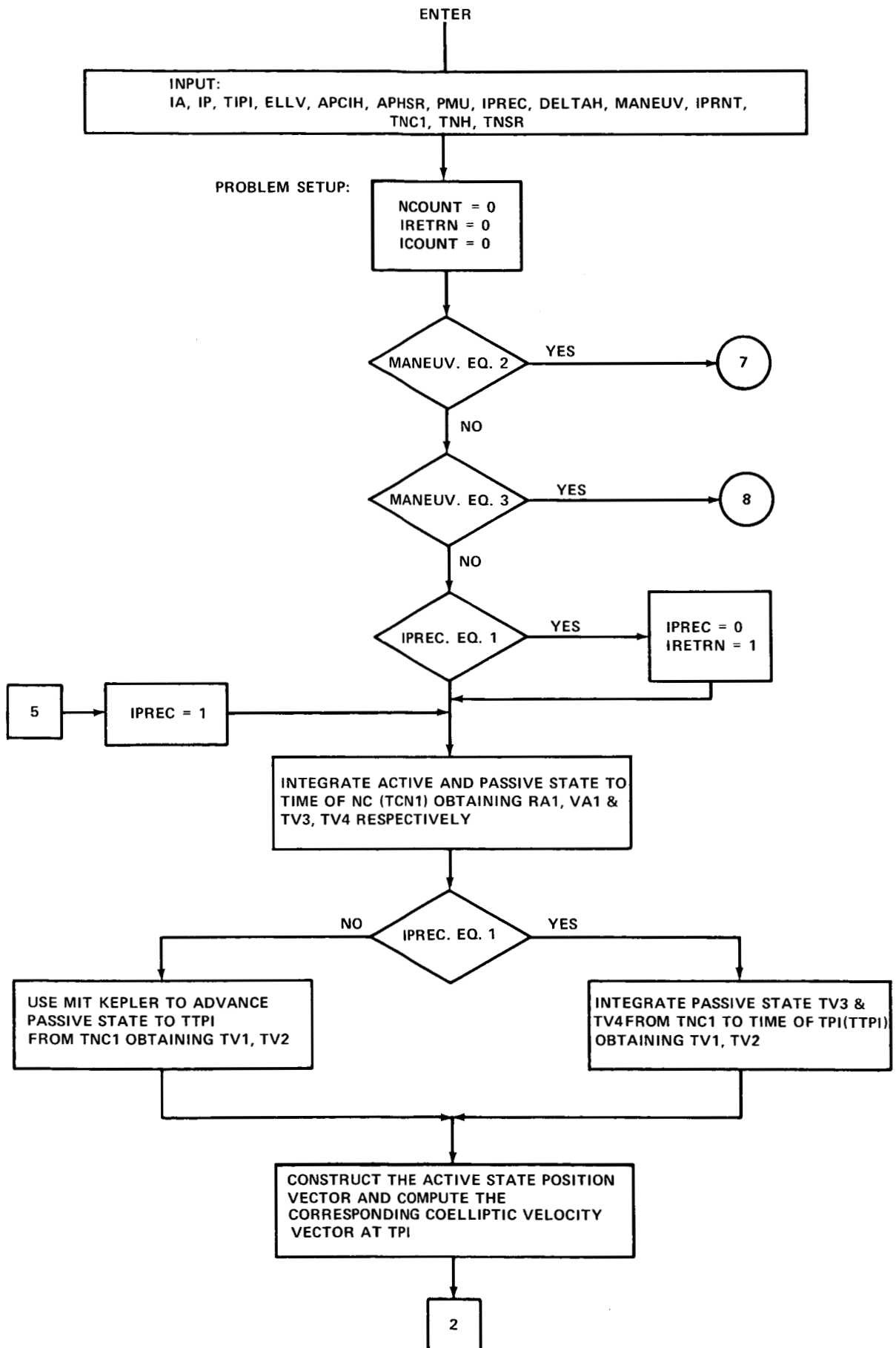
Subroutine THREE performs the computation of the NC/NH/NSR sequence. The logic flow diagram that follows shows the steps involved for each maneuver.

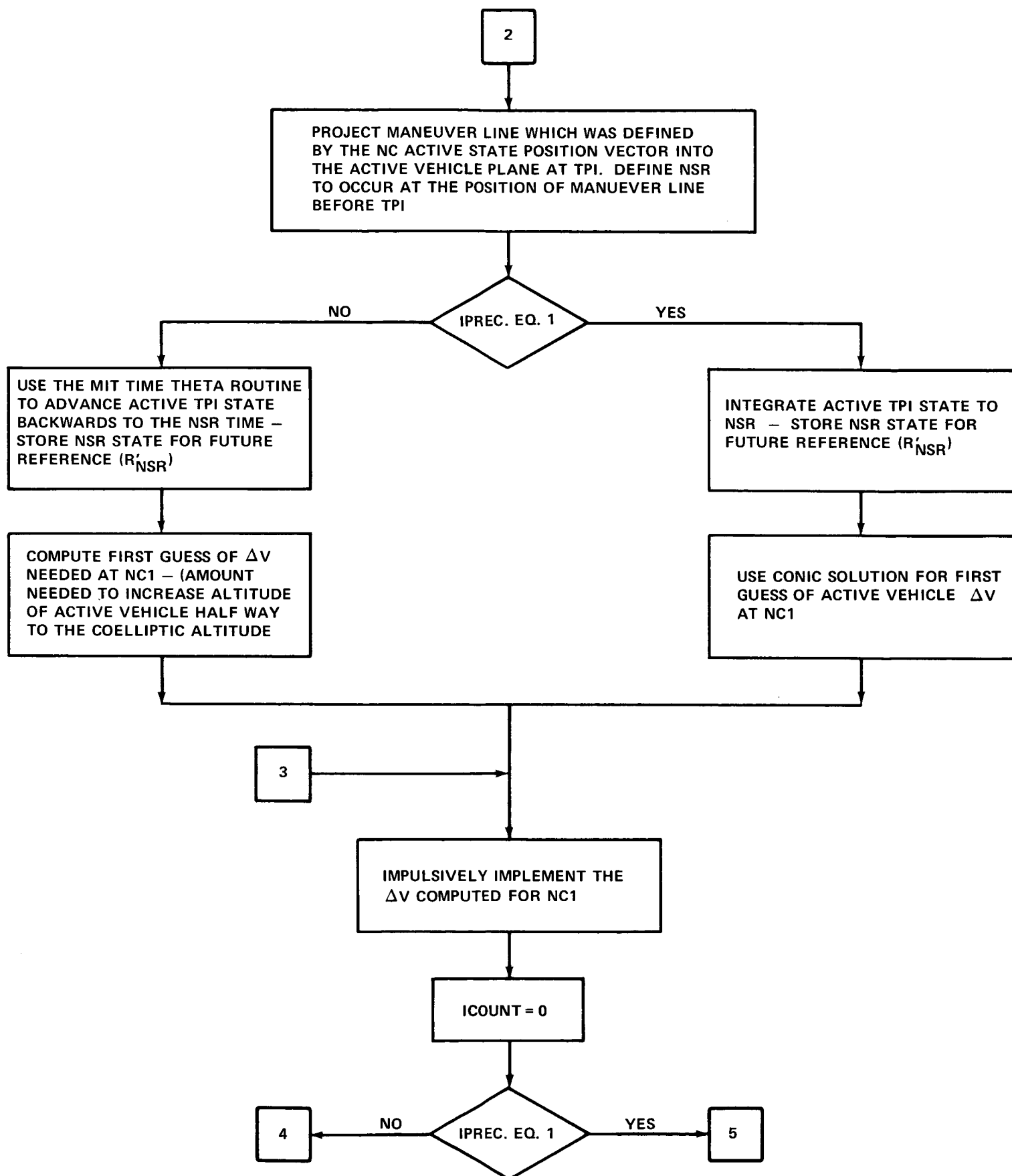
The routine utilized the MIT Conic Subroutines (Reference 3) that are used in the Apollo Guidance Computer for the conic calculations. These routines are presented in Reference 2. Subroutine THREE also uses a routine for advancing the state vectors by precision integration.

The flag indicating precision or conic calculation is IPREC. This flag is set equal to 1 for precision and 0 for conic calculations. If a precision solution is required, the flag is initially reset to 0 and a return flag 0 (IRETRN) is set. Upon convergence of the conic solution, the precision flag is set back to 1 and the calculations are again made using the sensitivities and delta-v's determined by the conic solution as initial estimates for the precision calculations.

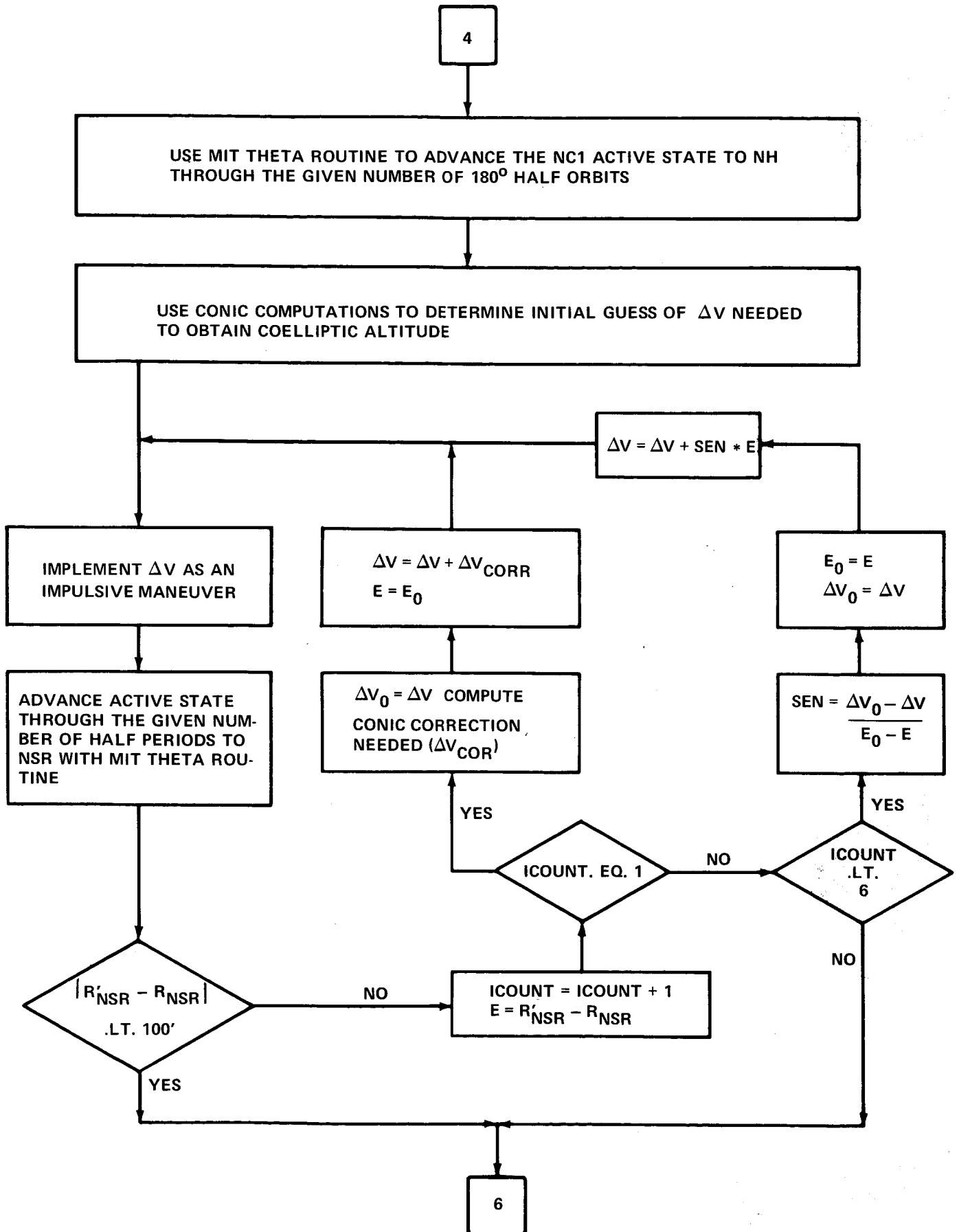
The maneuver flag (MANEUV) indicates the burn being targeted. The NC, NH and NSR maneuvers are coded 1, 2, and 3 respectively. Each of these maneuvers are independent computations. Therefore, if an NH or NSR maneuver is desired in some other profile, this routine may be used by setting the maneuver flag and then including the required input data given in Appendix A.

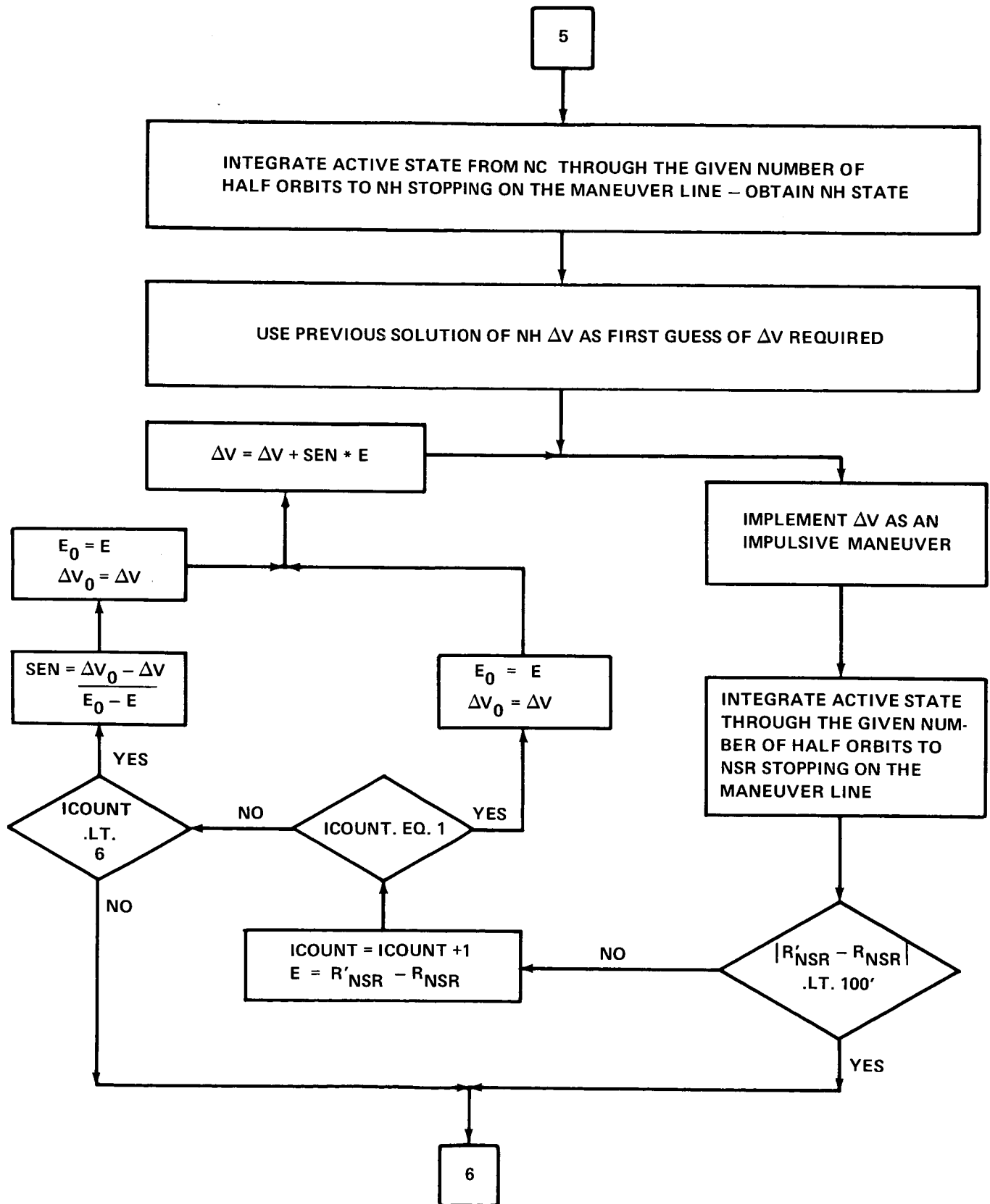
# SUBROUTINE THREE

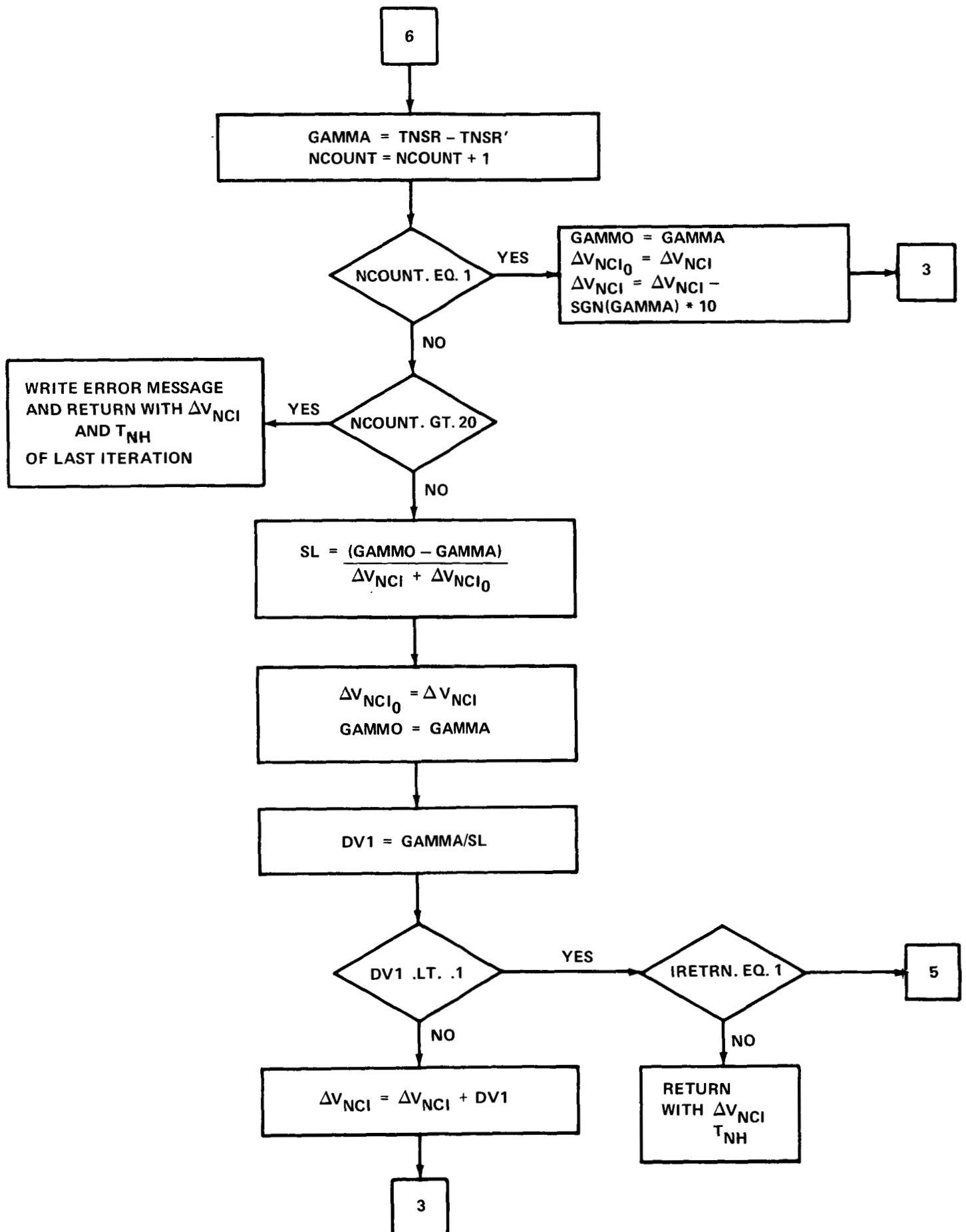


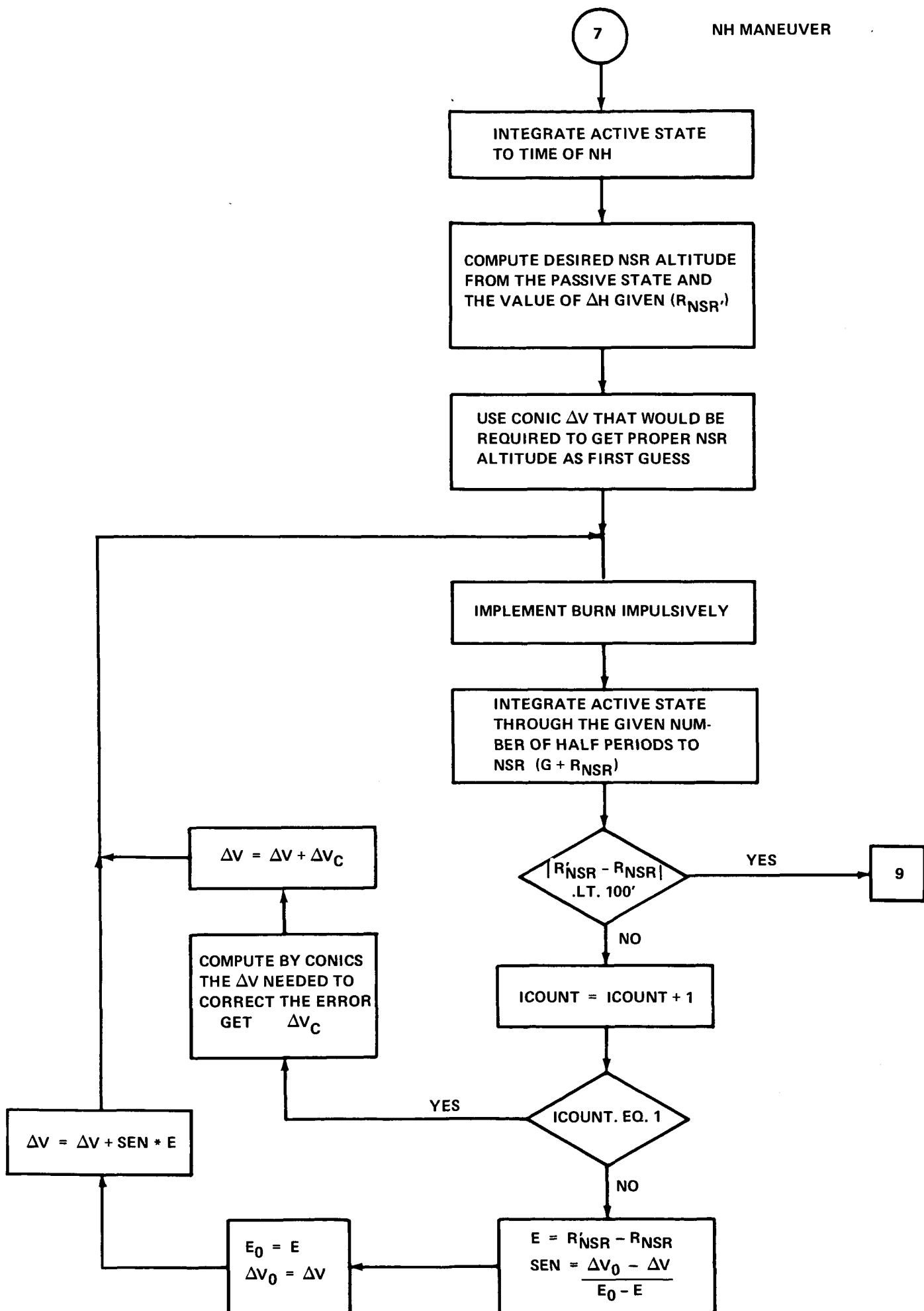


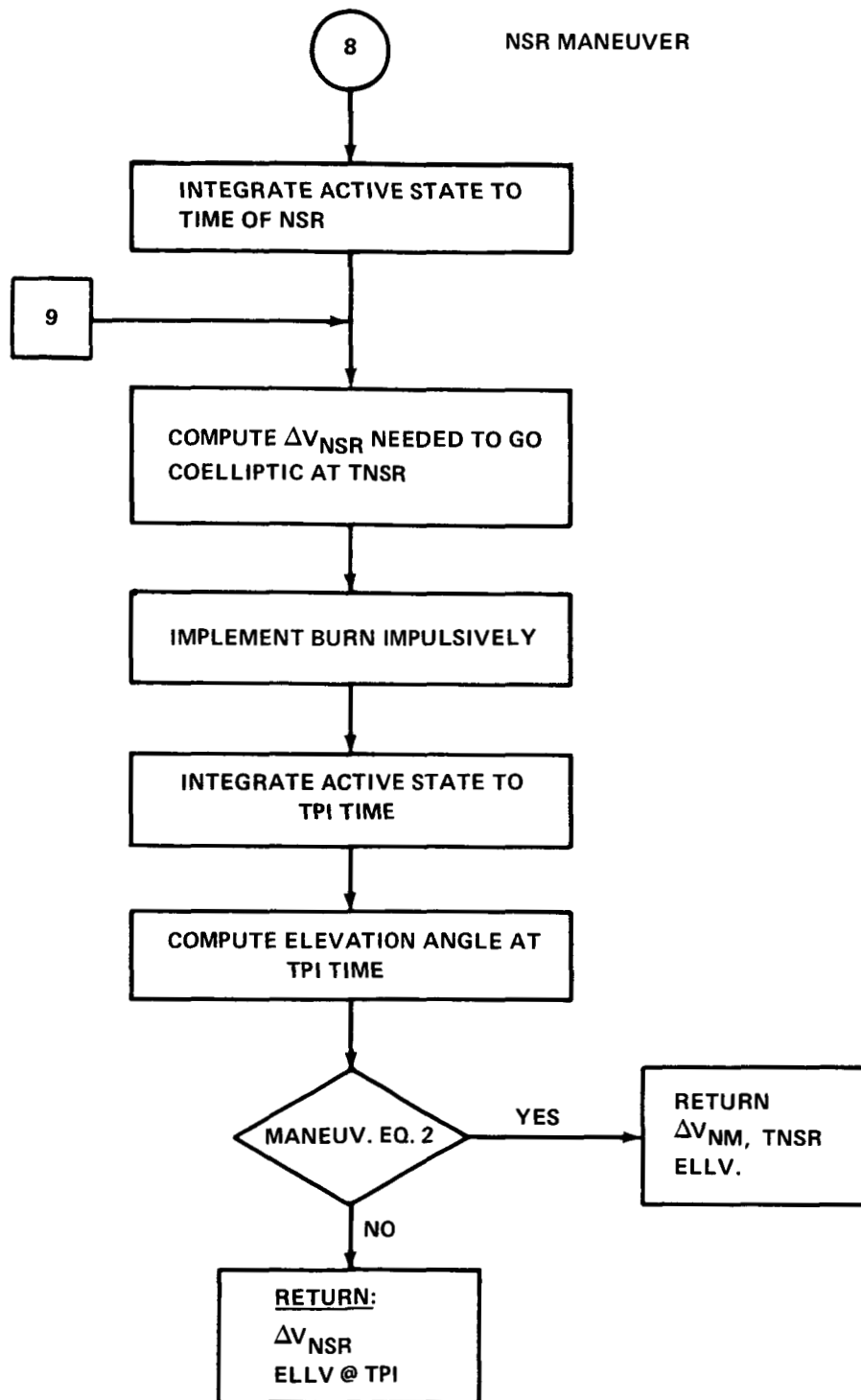












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